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LEAK DETECTOR FOR USE IN SPACE ENVIRONMENT

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16. ABSTRACT

Presented in this report are the design and manufacturing techniques and tests required to build a leak detector for aerospace hardware. The basic configurations and power requirements are described in detail and the application of a leak detector to aerospace hardware is explained.

The report shows that it is electronically, mechanically, and economically feasible to build leak detectors to support orbital inspection and checkout operations of large space stations and interplanetary vehicles.

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LEAK DETECTOR FOR USE IN SPACE ENVIRONMENT

SUMMARY

The task of developing a suitable leak detector to support orbital inspection and checkout operations of large space station and interplanetary vehicles was undertaken. The objective was approached in a four-phase effort: Phase I, prototype design; Phase II, prototype fabrication and test; Phase III, preparation of final production drawings of successful design; and Phase IV, fabrication of one pilot model.

The design phase of the contract resulted in a preliminary prototype design utilizing a cold cathode trigger gauge as a pressure transducer. The electronic subsystems are a logarithmic amplifier, a delay circuit, antilogarithmic amplifier for feedback, and a detector.

After the preliminary design had been developed and approved, a prototype leak detector was built and tested. Minor approved changes were made in the electrical and mechanical design. Then the contractor manufactured one production type model. This model was tested first by the contractor and then verified by personnel at Marshall Space Flight Center. Tests proved that the device could detect leaks as small as 7.7×10^{-7} SCCM in a vacuum of less than or equal to 1×10^{-5} torrs.

In addition to the capability of the leak detector to detect leaks from an orbiting body other features became evident. The device could also measure vacuum pressure over a range of 1×10^{-4} to 1×10^{-10} torrs and had the capability of detecting an outgassing from materials located in a vacuum. Other benefits from the device are thought to exist but have not been fully exploited to date.

The technical design and operation of the production model proved so successful that plans have been made to procure and test flight prototype hardware for performance evaluation and environmental qualification pending future funding.

SECTION I. INTRODUCTION

With the advent of orbital workshops and future extended space missions, a need for a suitable leak detector to support orbital inspection and checkout operations of large space stations and interplanetary vehicles becomes evident. Due to the environmental constraints of space, presently used instruments which operate under normal atmospheric conditions and require large amounts of electrical power cannot be utilized.

The purpose of this program was to develop a method of detecting external leakage from aerospace hardware while in a space environment and from this method design, build and test a system suitable for astronaut usage. The program was to be accomplished in a four phase effort: Phase I, conceptual studies and bench testing terminating in the selection and design of one or more concepts to be built; Phase II, fabrications and test prototype; Phase III, preparation of final production drawings of successful design; and Phase IV, fabrication of one pilot model, built to the formal documentation.

To ensure that the instrument would be suitable for use by an astronaut in space, several design and operational requirements were placed on the contractor. The criteria most pertinent to the success of the program were: (1) the system must be able to detect a leak of at least 1×10^{-6} cc/sec in a pressure environment of 1×10^{-4} torrs and an external temperature range of $\pm 250°$ Centigrade, (2) it should react to all common gases such as hydrogen, helium, nitrogen, oxygen, and organic vapors, and (3) it must be completely self contained, weighing no more than 3 pounds and have a volume of no more than 0.1 cubic foot.

SECTION II. PROTOTYPE DESIGN

A. Instrument Description

The Prototype Leak Detector, designed by Melpar, is basically a hand-held, self-powered, ion pressure gauge designed to operate in ambient pressures below 10^{-4} torr. Linear pressure measurements by the pressure detector (General Electric trigger gauge) are transformed into logarithmic electrical signals by the instrument electronics which are displayed as a deflection on the readout meter. Leaks are detected by noting changes in pressure when the trigger gauge is placed in close proximity of a leak. Since these changes in pressure are apt to be quite small, the meter pointer movement is more likely to be discernable when operating the instrument at low ambient pressures. Therefore, when searching for leaks, the instrument, upon actuating the buckout switch, simulates a low pressure indication by automatically subtracting an induced electrical signal from the signal which represents the ambient pressure. Electrically, this simulation is accomplished by using current (approximately one ampere per torr) to actuate the trigger gauge during operation. There are two sources of this current; (1) from the logarithmic amplifier which drives the readout meter, and (2) the buckout circuit. As more current is delivered from the buckout circuit, less current is delivered by the logarithmic amplifier and thus the readout meter moves down scale. In the prototype unit, buckout is applied in three discrete steps each time the buckout switch is depressed. Therefore, at an ambient pressure slightly larger than 10^{-7} torr, application of the middle level of buckout would also leave the meter sensitive to a small leak signal. However, at 5×10^{-7} torr, the largest buckout level would drive the meter off scale and the 10^{-7} level would reduce the reading to 4×10^{-7} torr, a reading at which a 10^{-8} deflection would barely be noticeable. Thus, when small leaks are to be measured in higher pressures, more buckout levels are needed, e.g., smaller discrete steps or a continuous buckout adjustment. In the production model, a continuous automatic buckout was used.

B. Detector

The heart of this system is the Detector, General Electric Model 22GT210 trigger gauge (cold cathode), shown schematically in figure 1. The gauge is self-triggering for pressures as low as 10^{-7} torr.

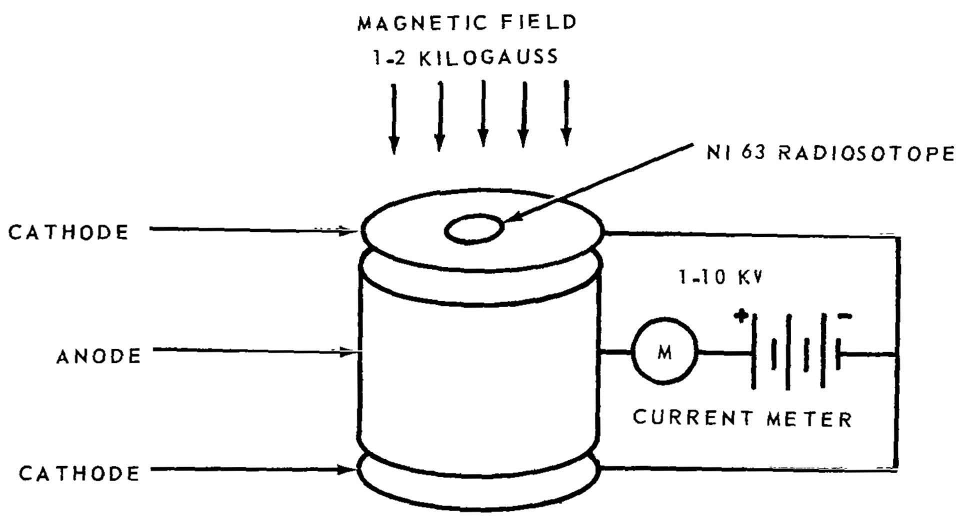

Figure 1. Schematic diagram of trigger gauge.

However, at lower pressures a discharge is often difficult to initiate. For the pressures lower than 10^{-7} torr, a filament or electron source is required to provide sufficient electrons to initiate a discharge. Although the power required by the filament would be of short duration (several seconds, generally), the additional current drain on the battery supply would be undesirable in a low power instrument. Therefore, a radioactive source was used in place of the filament, see figure 1. According to an article written by Chikara Hayashi appearing in Journal of Vacuum Science and Technology, a low intensity source of about 13 to 60 microcuries of Nickel-63 is sufficient to provide enough electrons to initiate a discharge. The intensity of the source used in the Prototype Leak Detector is approximately 60 microcuries.

C. Electrical Design

The Prototype Leak Detector electronics includes a battery power source, a 2000-volt power supply, a $\pm$ 15-volt power supply, detector, logarithmic amplifier, controlled temperature oven, buckout circuit, and readout meter. The logarithmic amplifier schematic is shown in figure 2 and its response in figure 3. In figure 2, A1 and A2 are Analog Devices 301 operational amplifiers, chosen for their high input impedance and excellent drift characteristics. Figure 3 shows the logarithmic response of these amplifiers over nine decades of input current, although the nine decades were traversed in two separate runs. The first step in taking the data was to apply 10^{-10} amperes input current and to set the amplifier output to zero volts. Run No. 1 was made, the data plotted, the output for 10^{-12} amperes input current was set to zero volts, and then Run No. 2 was made. The significance of the two runs is that the two linear plots on semilog graph paper can be superimposed to cover a full nine decades of input current in one run by adjustment of the logging amplifier. This amplifier was found to be more stable, require less power, and be more reliable and rugged than a conventional amplifier which utilizes a thermionic diode.

Further investigation into the logarithmic amplifier development revealed that, if the second operational amplifier was deleted and the readout meter was driven by the logging amplifier, a savings in component weight would be realized at no sacrifice in instrument accuracy. The logarithmic amplifier (breadboard configuration) was thus modified to the configuration shown in figure 4. The transfer characteristics of this logarithmic amplifier was linear from 10^{-10} to 10^{-4} amperes.

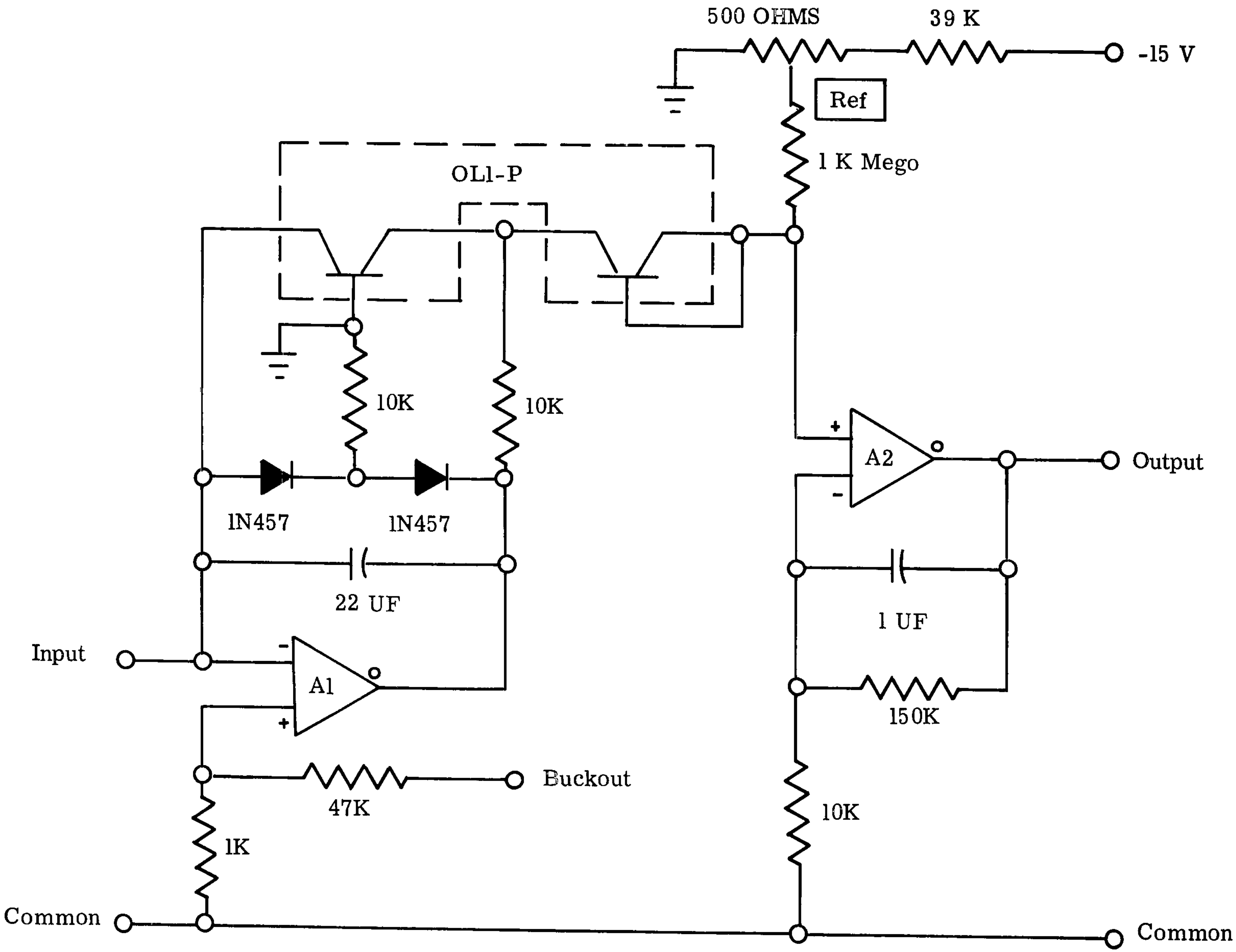

Figure 2. Logarithmic amplifier.

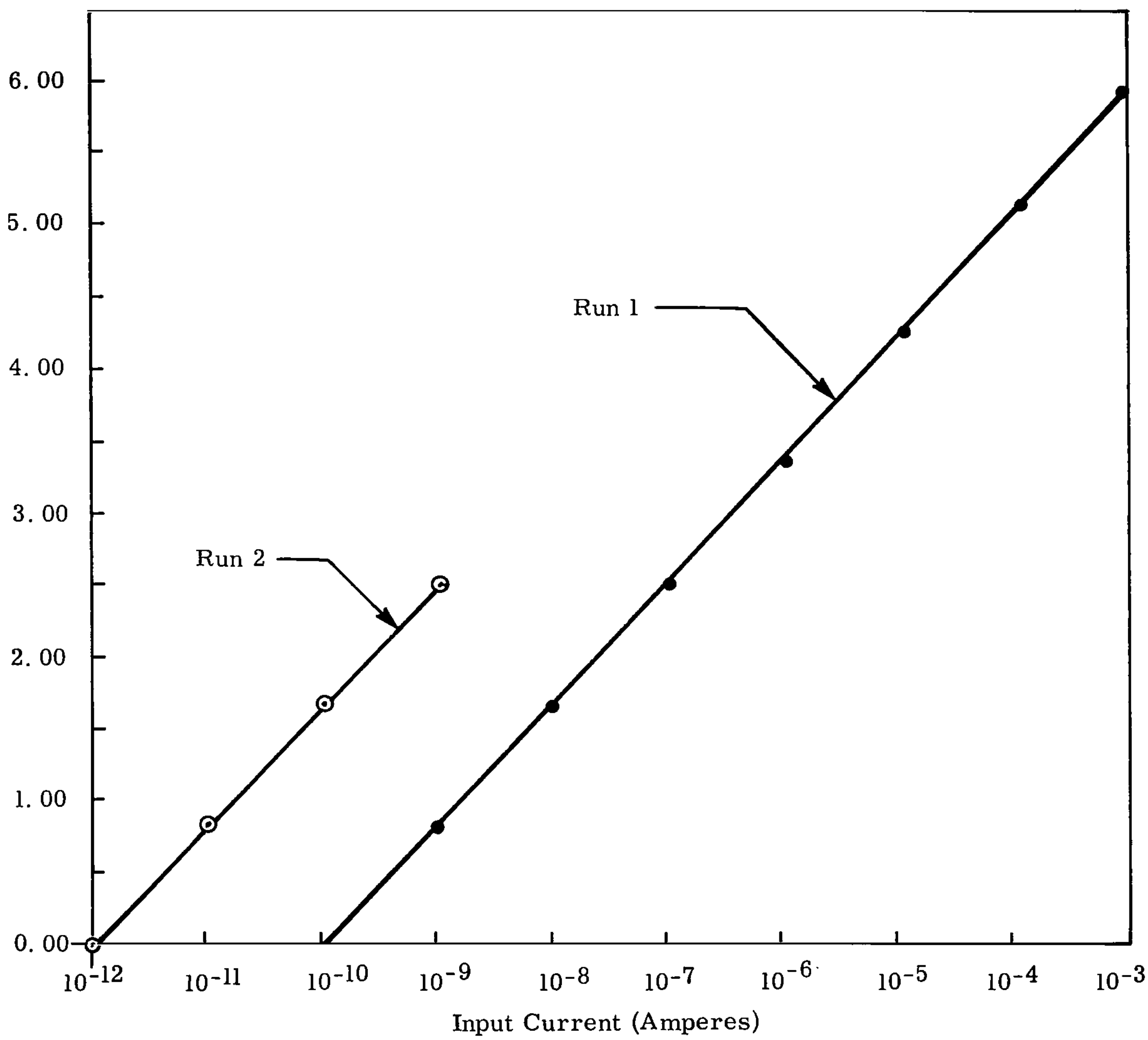

Figure 3. Logarithmic amplifier transfer characteristic.

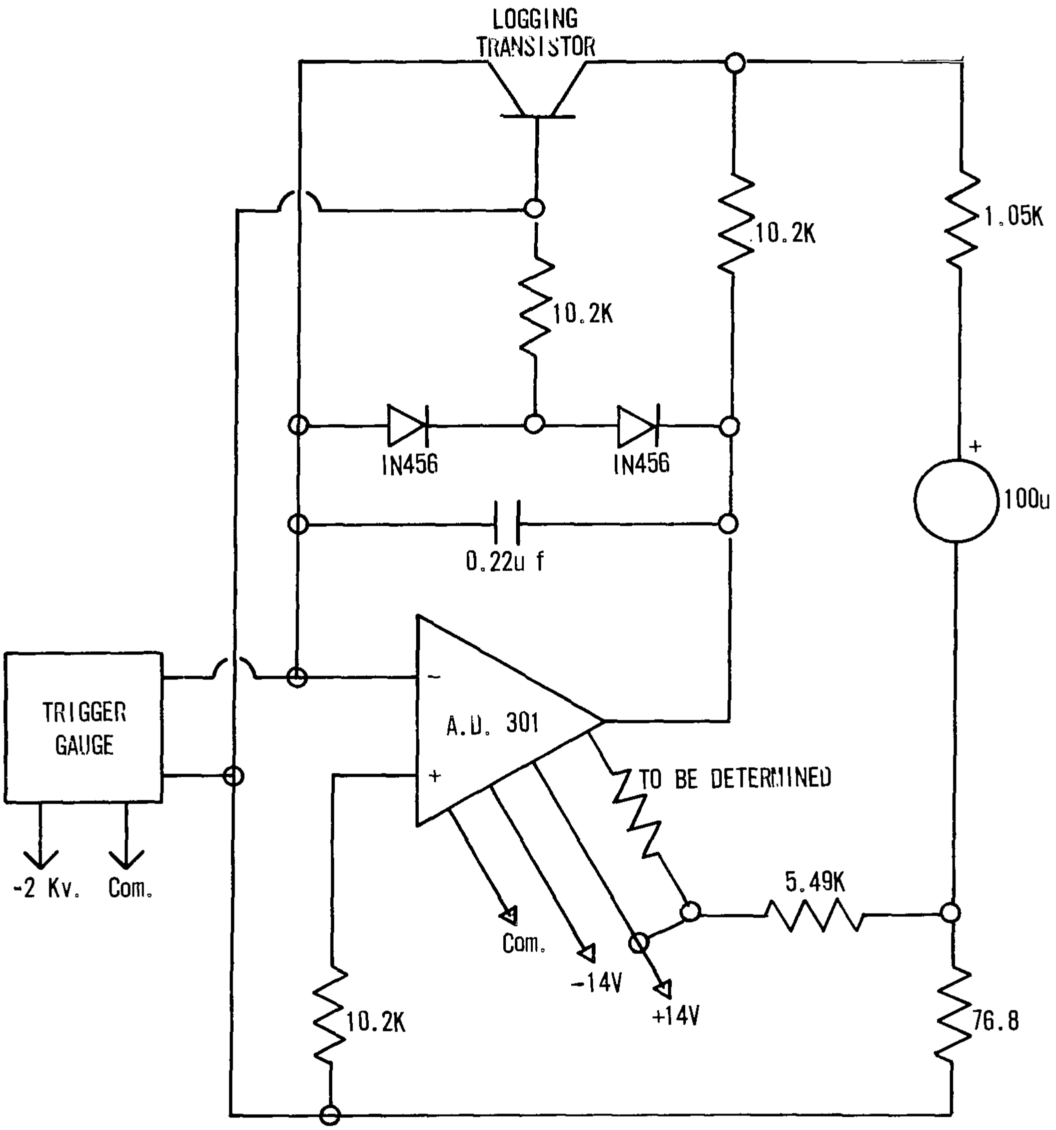

Figure 4. Modified logarithmic amplifier.

The logging transistor located in the feedback loop of the operational amplifier provided an emitter voltage output that was proportional to its collector current. The relationship between these two parameters was temperature dependent, therefore, a stable transistor temperature was required for accurate current measurement. The logging circuit used consisted of two matched transistors, on a common heat sink, that were potted together in an epoxy module. Since only one transistor was required for the logging operation, the other was used as a temperature sensor, making use of the change in V_{BE} versus temperature. This sensor is monitored by an operational amplifier (Fairchild µA709). This amplifier drives a transistor (2N1613) that controls the heater resistors in the oven. The two transistors and three 2000 ohm heater resistors are the only components in the oven that maintain a constant temperature near 50° C. The exact temperature is not important, but it is necessary that the temperature fluctuations within the oven be kept small. There has been no reason to believe that the temperature regulation has not been adequate; thus, no data is available on the temperature regulation.

In the absence of a suitable potentiometer, an alternate current feedback or buckout circuit was designed to be used in space and to allow current feedback to the amplifier. The range of buckout current was chosen to be from 10^{-4} to 10^{-6} amperes. Later, in view of the small response from the test leak, the range of buckout was changed to 10^{-6} to 10^{-8} amperes. Since it was not necessary to furnish a continuum of current values, three discrete levels were estimated to be sufficient. These three levels and one "off" level were initiated by a four-bit shift register whose parallel outputs furnished three inputs to an operational amplifier adder. The output from the adder was applied to the positive input of the logarithmic amplifier. The purpose of using the positive input of the logarithmic amplifier, was to by-pass the logging element (transistor) and supply a voltage equivalent to the logarithm of three decades of buckout current.

Later tests at MSFC proved that three discrete levels of buckout were not sufficient. A system which allows continuous buckout without operator intervention was then devised.

D. Mechanical Design

The design of the Leak Detector was based upon meeting the requirements for a small, lightweight prototype instrument. A small, lightweight, hermetically sealed meter or other indicating device could not be found; therefore, it was decided to use an unsealed meter and enclose it with the electronic circuitry and batteries within a sealed container.

The decision to seal the circuitry also alleviated the problem of dissipating heat from the electronic components since the case could now be backfilled with helium. The trigger gauge and the hermetically sealed switches in the handle are the only components exposed to space environment. Electrical connections from these to the sealed container are made through hermetically sealed feed-through terminals. All access covers are sealed using Viton O-rings which have a leak rate of less than 10^{-8} standard cc/sec of helium at the environmental temperatures and pressures expected.

The configuration shown in figure 5 was subjected to a thermal analysis which resulted in some minor changes in the location of some of the power dissipating components. The detailed thermal analysis is contained in the Appendix. The power supplies which account for the major portion of the heat are located in a trough at the bottom of the cylindrical section. To increase the heat conductivity from these components to the case of the instrument, they are held in place with a thermally conductive adhesive on the bottom and sides. A flat aluminum plate is placed on top of the power suppy to further assist in conducting the heat to the case.

The batteries and electronic circuitry are located on a chassis which is cantilevered from the rear cover. To minimize any adverse effects of this type of mounting during the shock and vibration environment, the end of this assembly is supported on all sides by a ring spring similar to those commonly used for RFI shielding. These components are made accessible for service or repair by removing the screws from the rear cover, sliding the assembly out until the first wire clamp can be removed after which the entire chassis can be removed from the case.

To facilitate removing the chassis from the case during debug, the ring spring was removed and since it was known that the prototype unit would not be subjected to any shock or vibration tests, the spring was not replaced.

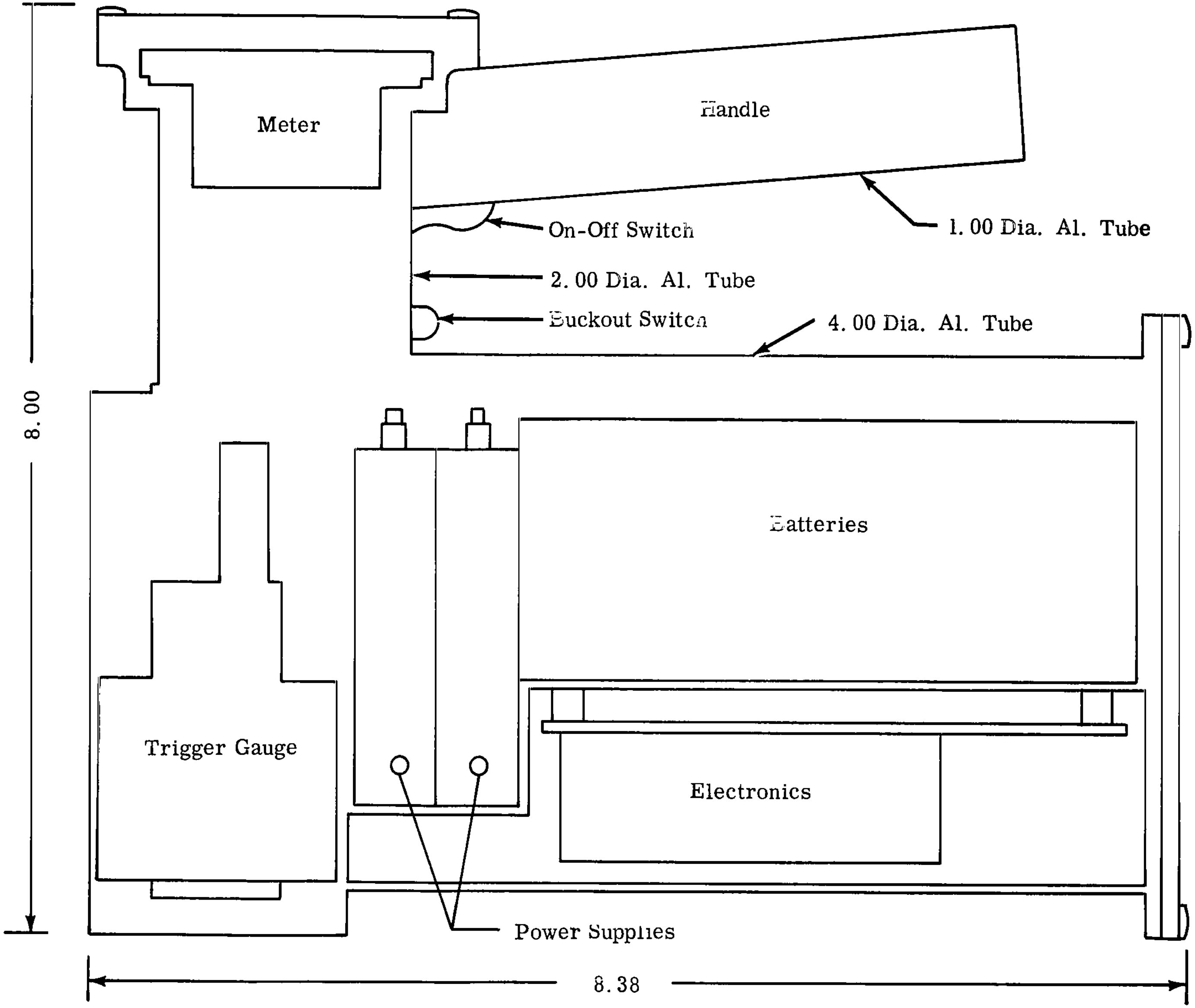

Figure 5. Initial design of leak detector case showing component location.

The case is fabricated from aluminum alloy and all seams are welded. A synthetic rubber septum located on the rear cover is used to evacuate the case and backfill it with 1/2 atmosphere of helium.

Information regarding the size of the astronaut's glove that would ultimately be used was not available; therefore, the handle was designed to facilitate Laboratory use. The on-off control switch is located on the bottom side of the handle and must be fully compressed for continuous operation of the instrument. The buckout control switch was located on the top side of the handle where it could be operated by the user's thumb. In the final design, the on-off control switch will be of the toggle type so that for continuous operation it is only necessary to push the bat handle forward where it will remain until it is manually retracted to the off position. Modifications to the mechanical design for the production model were minor and only for ease of handling by the suited astronaut.

Modifications to the General Electric trigger gauge were required to reduce its size and provide for a more suitable mounting arrangement. In addition, the filament was removed and replaced by a small piece of Nickel-63 radioactive material.

SECTION III. FINAL ACCEPTANCE TEST PROGRAM

After the preliminary design had been developed, a prototype was fabricated and tested. Tests proved that the instrument could detect O_2 leaks of as small as 1×10^{-6} standard cc/sec over pressures ranging from 6.1×10^{-8} to 1×10^{-5} torrs. Minor changes were then made in the electronics and mechanical structure. Electrically, the continuous buckout was added. Mechanically, the instrument was reproportioned to better fit the astronaut's hand. A production model leak detector, figures 6 and 7, was then built and tested. Testing was first conducted by the contractor and then the leak detector was turned over to MSFC for further test and reverification.

A. Contractor Test Program

The contractor test program consisted of leak testing of instrument case and functional acceptance tests.

1. Leak Testing of Instrument Case. Upon completion of fabrication and prior to chemical plating, the instrument case was subjected to a helium leak test to validate the integrity of the welded joints, O-ring seals, and electrical feed-through header.

The trigger gauge and header and end cover were assembled with their appropriate O-rings, and the unit was pressurized to 15 pounds above atmosphere. This pressurization procedure was to simulate the pressure differential which the unit would experience when operated in a vacuum environment with the internal pressure of the instrument at one atmosphere.

Tests for small leaks were performed with a Consolidated Vacuum Corporation Type 24-120A helium leak detector. This leak detector is equipped with a "sniffer" or sampling probe which continuously samples the air and/or search gas at the tip of the probe and passes it to the leak detecting element.

A small leak was noted at the O-ring seal of the end cover. After proper torquing of the mounting screws the leak rate dropped off to 1×10^{-8} standard cc/sec and remained constant at that rate.

Figure 6. Flight configuration (rear view).

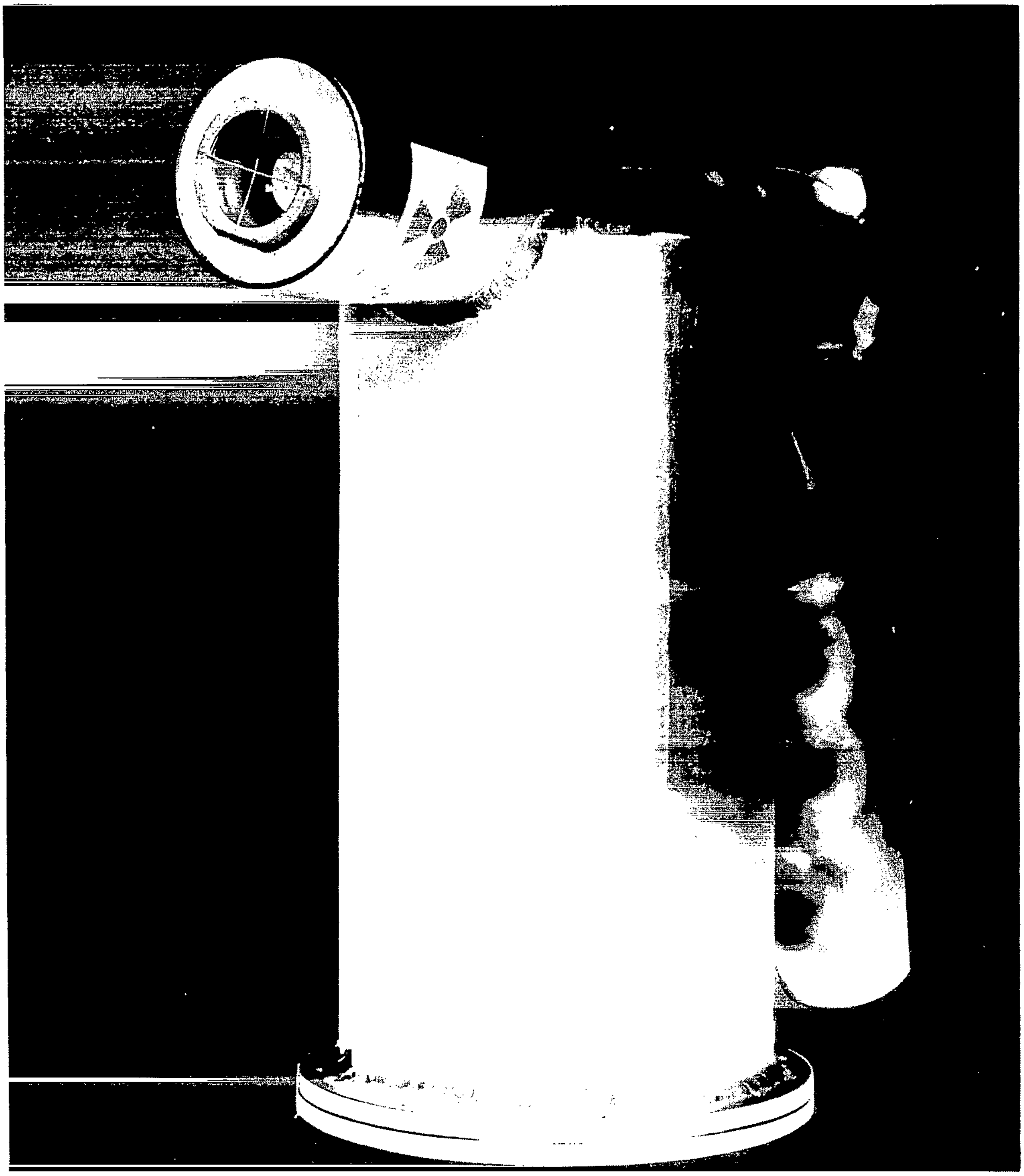

Figure 7. Flight configuration (front view).

A second test was performed using the evacuation apparatus in conjunction with a mercury manometer. The case was attached to the Melpar Gas Filling unit and evacuated and backfilled with helium to a pressure of 380 mm Hg. After a period of 20 hours, the pressure had dropped to 379 mm Hg.

The total leak rate of the case was determined by the rise in pressure as indicated by the mercury monometer with respect to time. This was computed to be a leak rate of 4.75×10^{-5} standard cc/sec based on a total case volume of 1.3 liters.

It was determined that this leak rate was acceptable and would be improved significantly when the final plating finish was applied.

The Leak Detector was completely assembled and subjected to a functional leak test to assure sealing integrity. The interior of the case was thoroughly purged with helium to remove all entrapped air and sealed at the end cover. The helium pressure in the interior case was one atmosphere (760 mm Hg).

The detector was then mounted in the vacuum chamber and the vacuum pressure reduced to 8×10^{-7} torr and allowed to remain at this pressure for approximately 10 hours. Upon removal of the detector from the vacuum chamber, a pressure measurement was taken to determine if a pressure loss had occurred over the 10-hour time period. The gauge pressure read 760 mm Hg, and no change was detected. The results of this test affirmed the fact that the unit is operational in a high vacuum environment without any significant loss in internal pressure.

2. Functional Acceptance Test. The Leak Detector was mounted in a medium volume vacuum chamber and was connected to an external power supply of 28 vdc in lieu of using the self-contained batteries. It was then tested for response to a calibrated oxygen leak of 7.7×10^{-7} standard cc/sec. It was also checked for pressure readout as compared to a calibrated vacuum ionization gauge.

The Leak Detector was subjected to three different test chamber pressures. These were in the range of (1) 1×10^{-6} torr or $<1 \times 10^{-6}$ torr, (2) 1 to 3×10^{-5}, and (3) 5 to 8×10^{-5} torr. At each pressure range, four readings were recorded to establish a net response at each range for the oxygen leak detection. This was performed by turning the external power supply off and then back on before each test. While at each of these pressure ranges a reading of the chamber pressure was recorded from the calibrated vacuum gage as compared to the meter reading of the Leak Detector. The oxygen leak was then passed in front of the detector and the meter deflection reading was recorded.

The test was performed as stated above. The instrument was subjected to pressures from 2×10^{-7} to 9.7×10^{-5} torr. The response of the Leak Detector to vacuum pressure and to the calibrated oxygen leak, with a leak rate of 7.7×10^{-7} standard cc/sec, was recorded as the oxygen leak was moved past the trigger gauge.

The data shown in table 1 are the results of the performance of the Leak Detector as a vacuum gauge and as a leak detecting instrument. The results of the four tests performed show good reproducibility. The accuracy of the pressure indications of the Leak Detector are low by about 1/2 log but may be adjusted to the correct value by changing scaling resistor R11 on amplifier Board A1.

The net response of the Leak Detector as a leak detecting instrument is given in table 2. The net response was determined from the data given in table 1, by subtracting the initial meter reading from the meter deflection that was obtained with the oxygen leak. The average net response at different pressure levels is approximately 4.14×10^{-9}.

Since the Leak Detector has only one level of buckout, the responses denoted with an asterisk were observed but could not be interpreted with any accuracy.

One negative reading in Test No. 2 occurred at the 2×10^{-7} vacuum range. This was indicated by a lack of positive response of the meter as the oxygen leak was positioned in front of the trigger gauge. This was possibly due to leakage current from the heater to the logging transistor which would result in a negative response.

TABLE 1. LEAK DETECTOR ACCEPTANCE TEST RESULTS

Test Chamber Press. Range	TEST NO. 1			TEST NO. 2			TEST NO. 3			TEST NO. 4		
	Gauge Vac. Press.	Initial Meter Reading	Meter Defl. W/ Leak	Gauge Vac. Press.	Initial Meter Reading	Meter Defl. W/ Leak	Gauge Vac. Press.	Initial Meter Reading	Meter Defl. W/ Leak	Gauge Vac. Press.	Initial Meter Reading	Meter Defl. W/ Leak
$\leqq 2\times10^{-7}$ TORR	1×10^{-7}	$<1\times10^{-10}$	6×10^{-9}	8×10^{-8}	$<1\times10^{-10}$	0	8×10^{-8}	$1\text{-}2\times10^{-10}$	6×10^{-9}	8×10^{-8}	$1\text{-}2\times10^{-10}$	6×10^{-9}
$\leqq 1\text{-}3\times10^{-5}$ TORR	5×10^{-6}	5×10^{-10}	3×10^{-9}	5×10^{-6}	5×10^{-10}	3×10^{-9}	6×10^{-6}	5×10^{-10}	3×10^{-9}	6×10^{-6}	7×10^{-10}	3×10^{-9}
$\leqq 5\text{-}8\times10^{-5}$ TORR	1×10^{-5}	2×10^{-9}	Yes	1×10^{-5}	2×10^{-9}	Yes	1×10^{-5}	2×10^{-9}	Yes	1×10^{-5}	2×10^{-9}	Yes
7×10^{-5}	2×10^{-5}	2×10^{-8}	Yes									

START TEST 1:45 March 28, 1969

END TEST 2:20

WEIGHT OF UNIT (LESS BATTERY FLUID) = 2850 grams

TESTS PERFORMED BY: J.W. Paljug
S.S. Brody

WITNESSED BY: K. W. Woodis

TABLE 2. NET RESPONSE OF LEAK DETECTOR TO OXYGEN LEAK

Average Test Chamber Pressure TORR	NET RESPONSE OF LEAK DETECTOR			
	Test No. 1	Test No. 2	Test No. 3	Test No. 4
2×10^{-7}	5.9×10^{-9}	0	5.85×10^{-9}	5.85×10^{-9}
2×10^{-5}	2.5×10^{-9}	2.5×10^{-9}	2.5×10^{-9}	2.3×10^{-9}
6.5×10^{-5}	*	*	*	*
9.7×10^{-5}	*	-	-	-

*Asterisk designations are nonreadable values of meter deflection resulting from limited buckout of electronics.

B. MSFC Test Program

Since the contracting officer's technical representative witnessed the final acceptance functional tests, a minor amount of inhouse tests were performed at MSFC once the leak detector was received from the contractor. These tests were to determine if any damage had occurred during shipment and to see if the contractor's test results could be duplicated. The inhouse test results proved that the instrument was technically sound and the results could be duplicated.

SECTION IV. DESIGN REQUIREMENT FULFILLMENT

Table 3 shows a comparison of the requirements imposed on the contractor when the contract was let and the characteristics of the production model leak detector delivered to MSFC at the close of the contract. Although the obtained values in many cases were not to the expectations of the required, the contract is considered highly successful technically. The final mechanical configuration is shown in figure 6.

In addition to the capability of the leak detector to detect leaks from an orbiting body, the device designed had several nice inherent advantages. One was the capability to read atmospheric or vacuum pressure over the range of 1×10^{-4} to 1×10^{-10} torrs. Also, the device has the capability of detecting outgassing from materials in a vacuum. Other benefits from the device are thought to exist but have not been fully developed to date.

TABLE 3. CONTRACTOR COMPARISON REQUIREMENTS

Parameter	Required	Obtained
Weight	1360 grams	2850 grams
Volume	172.8 cubic inches	171.25 cubic inches
Leak Detection	1×10^{-6} standard cc/sec @ 1×10^{-4} torr	7.7×10^{-7} standard cc/sec @ 1×10^{-5} torr
Ambient Temperature Range	$\pm 250^{\circ}$ Celsius	$\pm 250^{\circ}$ Celsius

SECTION V. CONCLUSIONS AND RECOMMENDATIONS

The development of a leak detector designed specifically for use in outer space has proved to be highly successful. A thorough concept study and preliminary design resulted in a product with a performance considered to be excellent though not meeting the precise requirements. A firm basis exists for building flight hardware for use in space.

The next step to be taken is the procurement and testing of flight prototype hardware for performance evaluation and environmental qualification. Plans are being made to initiate this effort in fiscal year 70. With successful accomplishment of this follow-on, the final effort will be a flight experiment or engineering demonstration.

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812
904-21-03-11-10

APPENDIX

THERMAL ANALYSIS OF THE PORTABLE LEAK DETECTOR PROTOTYPE DESIGN

A. Summary

The evolution of the reference design was monitored and checked with regard to the maintaining of electrical components in the package within a specified temperature range during operation of the unit. The critical components considered in the analysis were the SMU converters, the amplifier and adjacent circuit board, and the constant temperature cell (ctc). An operational temperature range of 0° C to 70° C, which is within manufacturer's tolerance, was maintained for all components with the exception of the ctc, which was maintained at 70° C at the periphery of the resistor cluster composing this unit.

The analysis that was performed consisted of the two operational extremes to which the instrument components will individually be subjected. These are steady-state full power operation at the maximum solar load for the component in question, and steady-state full power operation in the shade or dark space. No allowance was made for earth shine or reflection from the space vehicle; however, the configuration of components is such that the main cylindrical housing can readily accommodate the effects of this secondary radiation.

The following design recommendations are made based on the various analyses, which are outlined as follows:

1. The SMU units may be located in a rectangular trough along the longitudinal base of the main cylindrical housing, providing:

a. Positive metal to metal contact is ensured between the inner walls of the rectangular SMU housing which protrudes from the cylinder and both the main flat and edge faces of the SMU units themselves.

b. The outside of this SMU housing (the side strips and bottom face) is coated with thin film of a low absorptivity ($\alpha = 0.1$)

high emissivity ($\epsilon = 0.9$) coating system. ZnO pigmented K_2SiO_3 has such surface characteristics and would prove very durable for this application. ZnO pigment with an organic binder such as methyl silicone would be satisfactory.

c. The top face of the SMU units is clamped in place with an aluminum plate (about 1/8 inch thick) whose edges overlap the cylinder for approximately 1/2 inch to create additional cooling potential for the inner faces of the SMU's by providing a small fin effect.

2. The outer surface of the main cylindrical housing which contains the amplifier, circuit board, ctc, and batteries should ideally have a mirrored finish, both absorptivity and emissivity being as low as practical for a polished aluminum surface ($\alpha = 0.05$, $\epsilon = 0.1$). The only exception to this highly polished surface should be an area adjacent to the ctc unit which will be coated with a low absorptivity, high emissivity coating similar to that used on the SMU trough. If human factor considerations such as bright reflections override the adoption of a mirrored finish on top of the instrument (near the user) the SMU housing may be resituated on the "top side" of the instrument across from the handle. If reflections from such a configuration are considered too severe, some roughening of the surface could probably be tolerated to give a more diffuse surface, a supplementary calculation would be required to determine if heat from the SMU units could fully compensate for the higher emissivity and subsequent heat loss from the cylindrical section of the unit.

3. The ctc should be located adjacent to the shell of the main cylindrical housing. A small outside square corresponding to the face of the ctc should be coated with the low absorptivity, high emissivity paint used on the SMU's. This ensures that a net flow of heat (0.15 to 0.20 watts), is dissipated to space. This assures that a positive temperature control is exercised within the ctc at all times.

B. Discussion

SMU 2, SMU 028, and the amplifier have an internal source of 2.46 watts, 1.98 watts, and 0.336 watt, respectively. The ctc can release one watt of internal energy at maximum. The ctc is located above the circuit board which divides the main cylinder into two parts, below which the amplifier is installed. The void volume inside the cylinder is filled with helium at 5 psia.

In the preliminary design, the two SMU units were located adjacent to one another inside the main cylinder, near the ionization detector. The internal temperature of these components was found to be in excess of their specified range of operation (T_{max} = 110° C). Several alternate configurations to mount the SMU within the cylindrical housing were investigated; however, each produced excessive temperatures in the SMU's. The installation of the SMU's in a trough along the main cylinder which represents the final design configuration yields operational temperatures in the required 0 - 70° C limit. In full solar load, the temperature distribution across the 2.5 watt SMU unit ranges from 34° C at the outer edge to 71° C at the back face midpoint. When totally in the shade the 2.0 watt unit will have an outer edge temperature of about 7° C while the back face midpoint temperature should be 23° C. An absorptivity of 0.1 and emissivity of 0.9 were assigned to the radioactive surface characteristics of the SMU trough during the conservative two-dimensional analysis which was performed on these components.

In order to handle the complicated three-dimensional geometry of the instrument package in an expeditious manner, the physical case was resolved into simplified one- and two-dimensional analytical models. The models were selected in such a manner as to closely approximate the real situation and to yield conservative results for the specific case at hand.

The highest temperatures were associated with the maximum solar load beaming directly perpendicular to the largest face or container housing adjacent to the particular component in question, while the lowest temperatures were calculated with the entire unit radiating to black space. The heat transfer within theunit proper was assumed to be solely by conduction even in the helium blanket which surrounds the components. The instrument is assumed to be operated in zero gravity. Density gradients within the gas are ineffectual in inducing natural convection; the gas remains essentially stagnant.

The radiation self-shielding effect between the handle and the main cylinder was neglected, thereby introducing additional conservation into the calculation. Actual emissivities should be slightly higher than those recommended for this model simplification to compensate for ineffectual surface. This will probably be the situation with a typical polished aluminum surface, while the 0.1 emissivity value recommended is obtainable. The surface is more likely to be in the 0.15 - 0.20 range without elaborate preparation or preservation techniques.

For the reference design where the SMU's are located in the longitudinal trough, the SMU is assumed under maximum solar load; however, the actual amount of radiant energy which is reflected from the sun-side surface of the spacecraft to SMU when in actual use will be less than that calculated. Additional conservatism is introduced in the analysis of the SMU's by neglecting the heat transfer (1) from the inner SMU face through the inside of the main cylinder, (2) associated with the fin effect along the cover plate used to mount the SMU's in the trough housing, and (3) that capable of being radiated from relatively small end strips of the trough housing. Any natural or purposeful space tumbling would reduce the solar load from maximum levels.

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